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LOW COST MATERIAL SOLUTIONS FOR SOLDIER FLAME PROTECTION

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ABSTRACT

This summary describes the effort to develop low cost flame resistant combat uniform fabrics for use by service members of the U.S. Army. Fibers and fabrics investigated include: melamine (Basofil[R]), flame-retardant treated cotton (FRT), FRT cotton/nylon, FRT lyocell (Tencel[R]) rayon, FRT cotton/Kevlar[R]/nylon, carbonized rayon/Nomex[R], Kevlar/FR rayon, Nomex/FR rayon, PBI and PBI/FRT cotton. Instrumented manikin flammability testing was conducted.

1. INTRODUCTION

U.S. Army tankers, and aviators of all services, are required to wear flame resistant clothing systems made from Nomex/Kevlar fiber blend fabrics. Although these materials receive high user ratings, they are too expensive to issue to all military users. The infantry, which uses a nylon and cotton blend fabric, needs flame protection, but Nomex/Kevlar uniforms are too expensive to issue to every infantryman. The objective of the effort is to develop new materials and systems protection strategies that are affordable, quickly deployable, and improve the survivability of the individual soldier.

1.1 Flame Threat and Hazard Assessment

Prior to material development, the flame threat and hazard was investigated and characterized. It was determined that with the current state-of-the-art in materials, protection against a direct weapon hit could not be provided, but protection against secondary hazards and accidental flash fires is possible (Tucker, 1999).

1.2 Clothing Systems Test and Evaluation

Flammability test methods were reviewed and the thermal flux commonly used in the instrumented manikin test, ASTM F 1930, which is 2 cal/(cm^2 sec), is representative of the most common military scenario (Kim, 2000). Pass/fail criteria for the manikin test was established as "no more than a 20 percent body burn" based on military medical doctrine (Tucker 1999).

Testing was conducted on both tanker and aviator systems beginning with summer weight and adding clothing layers up to the winter weight configurations. The results are in Table 1.

Table 1. Exposure Limits for Military Clothing Systems

System	1	2	3	4
Layer				
One	T-Shirt, Briefs *Cotton*	Cotton or Nomex Long *Underwear*	*Nomex* Long *Underwear*	*Nomex* Long *Underwear*
Two	Coverall *Nomex*	Coverall *Nomex*	Coverall *Nomex*	Coverall *Nomex*
Three			Jacket *Nomex*	BibOverall *Nomex*
Four				Jacket *Nomex*
% Body Burn	< 20% at 3 sec	< 20% at 4 sec	< 20% at 6 sec	< 20% at 10 sec

Exposure limits increase with each additional clothing layer. The first line of defense against the flame assault is the outer-layer, which is flame and ignition resistant. Each additional clothing under-layer adds insulation and increases protection time. Tests performed with both cotton long underwear and Nomex long underwear show no difference in performance. These findings corroborate other studies (Capecci, 1995) demonstrating that the entire system, especially the under-layers, does not necessarily need to be made from flame resistant materials.

1.3 Material Development

The objective was to develop a fabric with low cost flame resistance, and provide the multi-functionality of the all-purpose combat uniform fabric currently in use, i.e. visual and near-infrared camouflage, comfort in climatic extremes, and durability and protection against the elements. Fibers, fiber blends and fabrics investigated and developed include: Basofil, FRT cotton, FRT cotton/nylon, FRT Tencel, FRT cotton/ Kevlar/nylon, carbonized rayon/Nomex, Kevlar/FR rayon, Nomex/FR rayon, PBI and PBI/FRT cotton.

1.4 Material Evaluation

Due to the camouflage requirement, many of the inherently flame resistant fibers were eliminated for use in a homogeneous fabric due to their highly crystalline morphology. The high polymer orientation of the aramids (Nomex and Kevlar), and PBI, which contributes to their flame resistance, also reduces or eliminates their ability to be dyed with traditional dyestuffs due to the lack of chemical dye sites. Some of these materials may achieve coloration by pigment injection in polymer form, but it limits their versatility. Still prized for their inherent flame resistance, these fibers were blended with low cost fibers to enhance the overall flame resistance of the fabric. Flame retardant rayon, which is inherently flame resistant rather than flame retardant treated, was blended with the aramids, but these materials fell short of the desired fabric strength, and colorfastness of the camouflage print. While the aramid fiber is the stronger of the two fibers, it occupied less that 50 percent of the total material composition to keep costs down. The strength of the fabric is dictated by the dominant fiber, which in this case, is the lower strength rayon.

Flame-retardant treated cotton has long been the industry standard for low cost flame resistant industrial work wear. However, the most commonly used treatment (Proban/Indura[R]) adds 20 percent to the weight of the fabric and weakens the cotton. Flame-retardant treated cotton and nylon fabrics, where the nylon is added to improve strength, are substantially higher in fabric weight but still do not demonstrate adequate breaking and tearing strength. In addition, heavier weight fabrics are known to contribute to decreased comfort and increased heat stress.

While all developmental materials meet the fabric bench scale flame test goals, strength and other durability related characteristics fall short. Basofil fiber demonstrated low fiber tenacity and developmental efforts were directed toward insulation, knitted headwear, and hand wear applications where high strength is not a critical factor. Core spun yarns were investigated and developed with the primary intent of manufacturing a yarn with a high strength, inherently flame resistant core, and low cost readily camouflage printable sheath fiber. The best performing material combination was a cotton sheath, Kevlar core yarn. These materials also fell short on strength because only the Kevlar-based core and not the sheath contributed to the fabric strength. Overall, the single best performing flame resistant fiber in terms of strength continued to be Nomex, but it was still one of the most expensive. The focus of the fabric development effort was changed from blends of low cost fibers and functional finishes to fabric and garment manufacturing methods. A novel approach was pursued to use the military standard grade Nomex/Kevlar blend but use non-woven fabric technology, which is direct fiber to fabric manufacturing, and save on yarn spinning, fabric weaving, and finishing and ultimately using a simplified over-garment design. A spun-laced non-woven fabric was developed by Dupont that provided strength that was equal to or greater than the former all-cotton Hot Weather Battledress Uniform (BDU) and half the weight. Due to it's lightweight, open, air permeable construction it can be worn over the existing BDU and together this configuration provides a 40 percent cost savings over the existing camouflage printed Nomex/Kevlar Aircrew BDU used by Army aviators.

Instrumented manikin testing demonstrated that when worn over the standard BDU the total body burn was reduced from 88 to 8 percent. Safe exposure limits up to 5 seconds were established. The non-woven Nomex outer-shell provides ignition resistance, and the under-layers of the BDU, t-shirt and briefs provide thermal insulation. The non-woven Nomex coverall is intended to augment the BDU system when flame resistance is needed and can be vacuum packaged for easy storage and transport

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CONCLUSION

A coverall made from spun-laced non-woven Nomex/Kevlar fabric can be worn over the BDU and together the configuration provides a 40 percent cost savings over the camouflage printed Nomex/Kevlar Aircrew BDU used by Army aviators. Instrumented manikin testing demonstrated that when worn over the standard BDU the total body burn was reduced from 88 to 8 percent. Safe exposure limits up to 5 seconds were established.